TITLE: Effects of Practice and Memory Aiding on Decision Performance and Information Search in Command and Control

Effects of Practice and Memory Aiding on Decision Performance and Information Search in Command and Control

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Abstract

This study examines to what extent practice (learning by doing) and memory aiding (paper and pencil) affects human decision performance and information search in command & control. A management command control task which simulates a dynamic competitive environment was used for this purpose. In six practice sessions memory aiding was systematically varied. 104 subjects participated in the simulation task. Their success score, failure score and decision speed score (number of decisions made per session) were measured as well as their information search profile. The results show that memory aiding led to a decrease of the number of decisions made and eventually resulted in a decrease in the overall success score. It led also to a decrease in the amount of information that subjects searched. Subjects used a satisfycing decision making strategy, using little information, which proved however to be successful in the long run. Practice resulted in a slight but significant increase in the amount of information search. However, most information was searched after the decision as a means of justifying the decision. It is concluded that memory aiding makes subjects spend too much time in problem structuring, at least relative to the dynamics of a complex command and control environment. The results are discussed in terms of cognitive continuum theory.

1 Introduction

A major issue in the performance of complex man-machine systems concerns the human decision processes in such systems. Complex man-machine systems share at least two essential features. First, the amount of information flow that is used for the decision making process is very large and the variables representing the information are directly or indirectly connected by a relational network which is often only partially known to the decision maker. Second, the decisions in these systems have to be made within a restricted amount of time. As a result human operators are often put in a situation of time pressure. High information flow and time pressure are two main characteristics of current complex man-machine systems, examples are command and control (C2) in military units, fire fighting units, medical teams and business dealing rooms.

Information load and time pressure make the decision process in C2 a task beyond the ability of a single individual. Therefore information has to be distributed over several individuals. The crucial question then becomes how an optimal distribution of information can be achieved so that efficiency and effectiveness in the decision making process is maximised. It is in this context of extreme importance for C2 design to assess what information is indeed relevant for the decision making process and what information can be eliminated. At the heart of these issue lies the crucial question that should be answered first: how much information can the decision-maker attend to when he or she is under pressure?

Almost 15 years ago, Andriole & Hopple (1986) proposed that issues of human factors, like the decision processes underlying C2, have been ignored by engineers and that the design and development of C2 systems has been dominated mainly by interest in technological advances. At the turn of the millennium, awareness for human factor issues has generally increased by designers and planners of C2. This realization of the necessity of human factors resulted in an increasing need for applied psychological research issues, among others the before mentioned question concerning how much information the decision-maker actually can deal with. This report focuses on this last issue: How much information do people use in assessing the value of a prospect in

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C2? How is decision performance influenced by practice and memory aiding? Is the information they search for used in an efficient way?

In the psychological literature the early studies of Einhorn (1974) and Ebbesen & Konecni (1975) have already shown that even expert decision-makers use only relatively little information in their judgements. It should be mentioned that these studies deal essentially with static, routine decisions without time pressure. When these results are generalised to C2 situations this may portray an unrealistic view. Still, the conclusions are striking enough. For instance, Einhorn (1974) showed that medical doctors use no more than three symptoms in their diagnostic process. Ebbesen and Konecni (1975), in a study on court psychology showed that judges did use not more than one to three aspects in their decision making process on sentencing defendants. Gigerenzer & Goldstein (1996) mentioned examples of experts using mainly one essential cue. Following Simon (1976), Gigerenzer & Goldstein's basic claim is that decision-makers are satisfycing. That is, all the decision-maker does is considering alternative courses of action sequentially until the first cue that 'will do' is found. As a potential explanation Geath and Shanteau (1984) suggested that many decision-makers have difficulties in distinguishing relevant from irrelevant information. Since irrelevant information needs attention as well, it becomes a heavy burden in information processing. Indeed, this may account for the earlier findings of limited use of information. This means that people use not only a limited amount of information, but also that irrelevant information may have a negative effect on the amount of relevant information that is eventually evaluated.

A related issue is that people seem to have an intrinsic tendency to search for redundant and irrelevant information. For instance, Lusted (1977) found that radiologists use information inefficiently. They search for additional information even when it is redundant and non-diagnostic. A likely explanation for this finding is that the information is not used during the decision making process itself, but that it is mainly applied for justifying the decision. That is, subjects do not use the information before the decision is made, but it is used afterwards, as a means of defending the decisions they have already made. This hypothesis is in line with Festinger's (1957) notion that decision making is mainly a search for justification. Festinger's work recently has gained a revival in the decision-making literature on post-decisional processes like regret and uncertainty reduction (Svenson & Benthorn, 1992).

An important question in this context is: What happens when the subject receives practice, e.g. learning by doing, and memory aiding during the decision task? Will subjects be able to search for more or different types of information and will decisional performance improve as a result? Or will subjects search only for more justification? This question is important not only from a theoretical point of view but perhaps even more for practical reasons. For example, the development of training programmes of C2 decision making is becoming increasingly popular. But the popularity of training programmes stems mainly from common sense notions like 'practice makes perfect'. In addition, most aiding devices that are planned and developed are often based on similar common sense notions. For example, memory aiding is supposed to reduce the workload, to support the representation of the environment and thereby improve decision performance. However, basing system design only on such notions is like relying more on belief than on facts, since there is hardly any evidence that in complex decision making under time pressure either practice or aiding will help. The results of the few studies available do not generally support the hypothesis that mere practice and aiding are beneficial. For instance, Broadbent, Berry and Gardner (1990) did not find any practice effects on decision performance in a complex command and control task.

There are several ways how practice and aiding can influence decision performance and the amount of information that subjects use. Take the following general scenario as an example. Suppose a decision-maker is confronted with a situation in which a series of prospects pass the scene. For instance, a series of potential threat alarms in military command and control. Or a series of buy options in a business dealing room. For each of these prospects the decision-maker can search for information about the value of the prospects, i.e. the seriousness of the threat or the (un)attractiveness of the offer in a number of ways. The decision-maker may search **locally** which of the prospects in one particular location or place is the most serious, and adjust the limited resources accordingly. Or the decision-maker may search more **globally**, that is over several locations, and assess the range of potential (un)attractive buyoffers or threats over different places. Finally, the decision-maker may assess the value of a prospect by taking information concerning **future** developments of the

system into account. A threat may represent a forebode of a potential larger threat, like the outbreak a war or the total collapse of the economy. So, the decision-maker can assess the value of a prospect by looking for more information locally, globally and for future developments of the system.

One approach towards learning and practice in complex dynamic decision making holds that suboptimality in decision performance is the result of insufficient knowledge of the decision environment or insufficient capacity to store information about the decision environment. As a consequence subjects are *forced* to rely on primitive heuristics (see: Kleinmuntz, 1985; Hogarth, 1981; 1987;Wickens, 1992). If subjects were able to improve their knowledge representation by searching for more information about the decision environment, e.g. by practice or by using memory aids, they would rely less on such primitive decision principles. They will gradually improve their decision performance by combining and integrating more information about alternatives and about threat dimensions and use this before the decision is made.

Table 1.1: Transfer table showing systematic variation of aiding and practice

No Aid	**Aid**
Aid	**No Aid**
Aid	**Aid**
No Aid	**No Aid**

This issue can be addressed by studying the transfer effects of a memory aiding manipulation. A transfer table is depicted in Table 1.1. which represents how memory aiding can be systematically varied with practice. Table 1.1. gives insight in the potential relationships between aiding, practice and decision performance. In particular, if memory aiding leads to the use of more information and to a better knowledge representation the following four questions are relevant: (1) To what extent does memory aiding improve knowledge acquisition? This question can be answered by comparing the performance of a group that does not receive any memory aiding (no aid –no aid) with a second group that starts with aiding which is removed in the second part of the experiment (aid-no aid). In the case of positive transfer memory aiding has promoted knowledge acquisition. If in the second group performance drops during the second part of the experiment to that of the first group, memory aiding has been useful but has not promoted acquisition of knowledge representation. There could be even negative transfer of memory aiding resulting from merely relying on aiding rather than acquiring a better representation. (2) Is memory aiding just a matter of extending working memory? This question can be answered by comparing the decision performance of a group that starts without aiding and receives aiding in the second part of the experiment (no aid-aid) with a second group that starts with aiding in the first part, and receives no aiding in the second part (aid-no aid). If memory aiding is only a matter of supporting the working memory the patterns of results for these two experimental groups should mirror each other. (3) To what extent is a successful decision performance possible without any memory aiding? This question can be answered by comparing a group that receives aiding (aid-aid) with a group that does not receive any aiding (no aid – no aid). (4) Is memory aiding only helpful after sufficient practice? This question can be answered by comparing a group that does not receive any aiding (no aid – no aid) with a group that receives no aiding in the first part of the experiment but only in the second part of the experiment (no aid – aid).

There is an alternative line of argument that stems from the notion that decision making is these complex dynamic decision making is best performed by intuitive cognition (Hammond et al, 1987). Hammond et al argued that cognitve tasks can be classified on a cognitve continuum. Some tasks are intuitive inducing others are analysis inducing. Some properties on intuition inducing tasks are: the number of cues is larger than 5 and there is a high redundancy and simultaneous display of cues. In addition there is a low certainty level in the task and the decision time period is brief. These are aspects which are all prototypical for C2 situations. C2 tasks are therefore prototypical intuition inducing tasks.

Intuitive cognition in decision making is guided by inbuilt satisfycing principles (Simon, 1957). Following a satisfycing principle subjects base their decision on the **minimal** amount of information needed to come to a decision. They focus mainly on the current and imminent options. As mentioned earlier, satisfycing means that the decision maker mainly considers alternative courses of action sequentially until the first cue that

satisfies a subjectively predetermined criterion is found. Subjects will take 'the first and the best' option. They neglect alternative options and evaluate on the basis of mainly one dimension or aspect, which may vary from context to context. It is obvious that this does not necessarily always lead to the optimal outcome, but the strategy is very flexible and may save much processing time. Indeed, the strategy may even prove to be highly successfull in complex and dynamic situations and it may even outperform a analytical decision making strategy (Hammond et al, 1987; Gigerenzer and Goldstein, 1996).

Performance improvement will be the result of a more differentiated value system, e.g. due to practice. This may result in changes in the minimal criteria chosen to evaluate an option as appropriate or not. In general, there is no expectation of an increase in the total number of alternatives and dimensions that are evaluated before the decision is made. The decision making process, even for experts, remains basically a process of satisfying principles, and it is even more likely that experts will use less information. For example, novices who try to find out what the causes are for a sudden dysfunction in their car appear to search for much more information than an expert repairman who may only need one or two cues.

Following this line of thinking one can be very sceptic about the effects of memory aiding that aim at promoting information processing, since it may slow down the decision making process. Thus, storing and saving more information for the decision making proces may increase the decision processing time and decrease decision flexibility in a dynamic environment. As a result of memory aiding subjects may consider more analytical judgement processes in the sense that subject may store more information which they may try to integrate in the decision making process. Consequently subjects decision performance can even be diminished as a result of memory aiding.

The concept of satisfycing has been demonstrated in numerous experimental tasks in the area of behavioral decision making (e.g., Simon, 1955; Huber *et al.*, 1990; Dörner, 1987; Gigerenzer & Goldstein, 1996). However, these demonstrations were solely based on static decision tasks. The concept of statisfycing has received little attention in the literature of complex dynamic decision making. In particular, the effects of practice (learning by doing) and memory aiding have received little attention. In fact, albeit the long history of complex and dynamic decision making, experimental studies conducted in this area are still relatively scant in general (Brehmer, 1987; Flin et al 1997; Kerstholt, 1996; Mynatt et al 1977; Roelofsma, 1995; Zsambok & Klein, 1997). In order to study the potential negative or postive effects of practice and memory aiding on decision performance and information search in a simulated C2 task, in the present study memory aiding will be systematically varied over a series of practice sessions.

There are several problems in regard to experimental studies with simulated C2 tasks. First, the task must capture the major characteristics of a generic C2 task, such as:

a) it should have an objective that is both well defined but for which there is also no simple strategy or solution.
b) performing the task should require analyzing several sources of information, that differ in aspects like timeline or modality.
c) the task should have a judgment component as well as a choice component. Subjects must assess a situation, evaluate it and diagnose it in order to make decisions.
d) the decisions in the task should be made within a restricted amount of time.

A second problem in studying aspects of practice and aiding is that the experimental task should neither be too simple nor too complex and there should be sufficient time for the subjects to acquire expertise in the task. Indeed, some of these problems may be the reason why Broadbent at al. (1990) did not find any improvement in decision performance as a result of practice.

A third problem is that the task should generate sufficient performance measures. For example, the task should generate a meaningful 'success' score. In military command and control this may refer, for instance, to the number of succesfully eliminated targets per unit of time. In dealing room C2, this could be expressed in the profit made per decision. Next, there should be an error or failure score, such as the amount of losses in military C2 or the number of bankruptcies in business C2. But it also should give a measure of decision speed, such as the total numer of decisions in a fixed amount of time. The combination of the above measures is

especially important for interpreting decisional performance in C2, since the decision maker may, for example, improve his success score, while at the same time the costs of the losses or the speed of the decision process become unacceptable.

Finally, in order to examine cognitive aspects like information search the task should generate a profile of the information that the decision maker uses before and after the decision. For example, information about the value of current and imminent prospects, as well as information about local, global and future values. A C2 task that meets these criteria is MILSIM developed by Van Doorne (1986) and this task was used in this experiment.

2 Method

Subjects. Hundred and four VU undergraduate psychology students applied to participate in this experiment in turn for study credits, equivalent to 40 hours study time. Subjects were aged between 18 and 23 years.

The C2-task. Subjects make trading decisions in a business command control simulation of a complex and dynamic trading environment. The game simulates a competition between several merchant fleets, each of which owns several shuttles and all of which are competing for trading opportunities. The headquarters of the fleet constitute a C2 system in which the market situation is continously assessed and decisions made concerning the portfolio (or consumption bundle) of the products in a spaceship. The goal of a decision maker (DM) in MILSIM is to maximize profit by buying products at centers that offer low prices and sell them at centers that offer higher prices. There are six trading centers and six commodities that can be traded. Each center sells three commodities and buys three commodities. A center does not buy and sell the same products. The demand and supply in terms of quantities as well as prices differ from one center to the other and are continuously changing as a result of the economic scenario's that evolve during the game. For that purpose constant information has to be obtained on the supply and demand of different commodites in each center and about the future developments of the environment. If the DM makes the right decisions the company will prosper and make large profits. Alternatively, wrong decisions may lead to losses and eventually to bankruptcy.

The structure of the game is as follows. The DM sits behind a computer screen. Then the DM receives information that a specific ship has landed on a certain centre in space. Next, the DM starts a so-called 'dialogue' with a simulated captain of the ship. We will refer to this action as SD (start dialogue). In this dialogue the DM will be sequentially confronted with three sell offers and three buy offers (prospects). That is one offer at a time. We will refer to the sell offers as S1, S2 and S3 and to the buy offers B1, B2, and B3. For each of the buy and sell modes the following information is presented to the DM on the dialogue screen. Some of the information can be crucial for a decision; other information is simply irrelevant. The specific contents of the information presented below is used only here to illustrate the procedures and this is printed in Italics:

1) The message containing the buy offer e.g.: 'Centre sells food'.
2) The quantity of the offer, e.g. '24 kugels'. (kugels is a fictitious unit for amount)
3) The price per kugel, e.g. '2000 / kugel'
4) The name of the centre location, e.g. 'Alcor'
5) The number of the center, e.g. '#cntr *2*'
6) The name of the ship, e.g. '*Our Mary*'
7) The ship number, e.g.'#sh *3*'
8) The name of the captain of a ship, e.g. '*Peter*'
9) The current date, e.g. 'Day:*14* Month: *4* Year *2525*'
10) Visiting time on center, e.g. 'Minutes: *4* Seconds: *0*'
11) The price of info, e.g. '*800*'
12) The ships money, e.g. '*80 000*'
13) The ships weight, e.g. '*25*'
14) Travel costs, e.g. '*4000*' per 100 starmiles
15) The commodities that the ship has on board. A table is presented on the screen which tells which product are stored on board and how many.
16) The weights of the products. This is also presented in a table.

17) The distances between the starcenters. This is presented in a star map.
18) The products that were bought on the current center. This is presented by two asteriks (**) in the commodity table.
19) The fuel price, e.g. '*1.8*'.

The travel costs are a function of the ships weight, the travel distance and the fuel price. The fuel price fluctuates, as well as the information prices. The ships travel time is a function of the weight of the ship, the distance and fluctations in the environment. For a description of the simulation model see table 2.1 in appendix II and Van Doorne (1986). Obviously, the DM is not aware of precise nature of the model.

Table 2.1: Overview of the experimental design

	3 * 1½ hour sessions	**3 * 1½ hour sessions**
Group I (n = 26)	No Memory aiding	No Memory aiding
Group II (n = 26)	Memory aiding	No Memory aiding
Group III (n = 26)	No Memory aiding	Memory aiding
Group IV (n = 26)	Memory aiding	Memory aiding

As can be seen in the list above the DM receives much information, but there is one aspect on which the DM is always left in uncertainty. This concerns the uncertainty related to the relative value of the current prospect, e.g. what is the value of 24 kugels of FOOD? To asses the relative value of the current option in B1 the DM can search for several pieces of information. First the DM can search for local alternatives. That is, the DM can purchase information on the alternative options of the center where the ship is currently located. This we have labelled **local** info. If the DM buys this info he receives the demand and supply of the current center in terms of prices and amounts. Alternatively, the DM can search for global alternatives. That is, he may search for information about the values of other products at other centers. We have labelled this type of information **global** info. Then the DM may search for the future value of products. We have labelled this info: **future** info. When the DM buys this info, information is presented on the future fluctuation of prices and quantities in the simulated economy, as well as development of fuel and gas prices and general travel times, potentials wars and disasters. The DM can also buy only the info concerning the value of the current offer under consideration. We have labelled this info **imminent** info. Buying imminent info about the product FOOD, for example, means that the DM receives info on the current demand and supply of FOOD in terms of buy and sell prices and the corresponding quantities. Of course, the DM may always decide not to buy any information at all and trust only on his intuition about whether or not to except the offer. The DM has to indicate about how much will be bought -if any- by entering the corresponding value. Entering the value 'zero' means that the DM refuses the offer. Then the DM automatically arrives in B2. The second prospect is offered and the whole precedure described under B1 is repeated. Next follows B3. The DM has in total 4 minutes to decide about his consumption bundle for B1-B3 together. When these 4 minutes have passed, or after the DM has finished with B3, the DM automatically comes in the so called travel destination mode (TD). Here the DM has to decide about the new travel destination for the ship. This decision has to be made within 30 seconds. When this time mode is surpassed the ship will be be charged with 2500. If the ship has insuffcient money to pay for the travelcosts the center will buy back the products that the DM had just bought. But now the currency will be only half of the price that the DM had just paid for. In the TD the DM can again buy each of the information types described above. We will refer to this type of information search: **after**. When the ships has insufficient money to make one more travel the company is bankrupt and the DM has to starts all over again.

The ship starts with an empty ship and a capital of 80 000. On the arrival at the new location the DM first passes the three sell modes. Then the Buy modes sequence starts all over again. We will refer to a complete decision round to a center as a **visit**.

Procedure. Subjects were tested in six sessions of 1½ hour. The sessions were divided over one week. Apart from these sessions there was a general instruction session of 45 minutes. In this general instruction session

the subjects read the general game scenario instructions (see appendix I). Next they learned how to play the game at a keystroke level. After this first general practice they were required to re-read the instructions for about 5-10 minutes. Six subjects were tested at a time in this experiment. They were visually separated from each other, although all subjects were in one large experimental room. The best out of each six players received a HEMA Dutch apple pie with a value of Fl 9.95.

Design. Subjects were randomly divided into four groups as is shown in Table 3.1. As mentioned earlier, these four groups are required to deal with the simulation game in six experimental sessions of one and a half-hour. The use of memory aiding was systematically varied within and between and subjects (see Table 3.1) in a standard transfer design. In the memory aiding condition subjects received paper and pencil to support the decision making and they were told to use it as a support for their decision making process. In the no aid condition no paper and pen were available for the subjects. Table 3.1 shows that subjects can start either with or without aiding and end with or without aiding. We will refer to this as the **begin aid** manipulation and **end aid** manipulation. The four groups we will refer to as **no aid-no aid, no aid-aid, aid-no aid and aid-aid.** By comparing the main and interaction effects of the begin aid and the end-aid manipulation with practice the potential positive or negative effects of aiding can be examined.

For each subject, the amount of vists in one session was measured, as well as the number of bankruptcies per session, the profit made per visit, the amount of info per visit. A MANOVA was used to analyse these results. The information types: imminent, local, global, future and no info were measured and an analysed descriptively over all groups.

3 Results

3.1 Profit making. In order to give an illustration of subjects' profit making behaviour a sequence chart is plotted in figure 3.1 for one of the subjects. The chart depicts the subject's profit for each subsequent visit. It can be compared with the 'heartbeat' of the profit making process. A reference line is printed at the mean of the series. For the particular subject in the figure it shows that profit gradually goes up with an occasional extreme peak down- or upward. These extremes are a potential problem for further statistical analysis when the mean is used as the measure for central tendency in techniques that require a normal distribution. The procedure that was followed in this study was to identify and exclude extremes relative to the distribution of the 'profit' variable over all sessions and groups. Explorative statistics with stem and leaf plots was used to achieve and justify this.

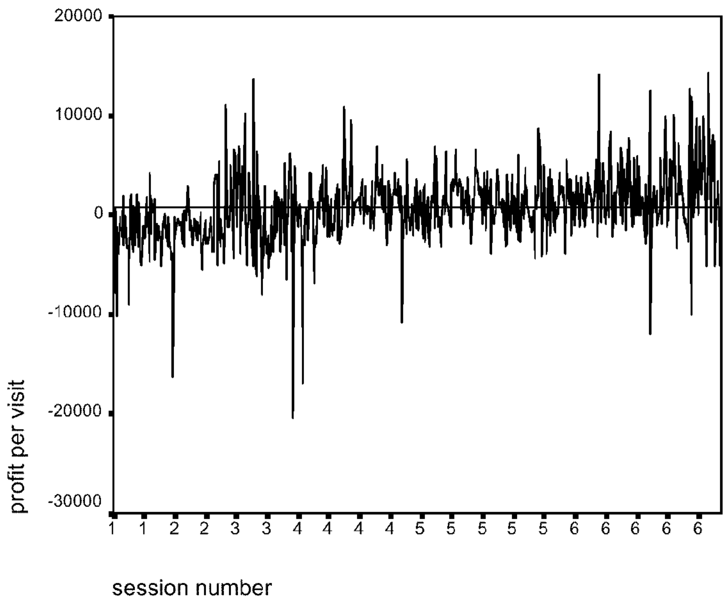

Figure 3.1: Profit Sequence Chart for subject no 16

In figure 3.2. and table 3.1 (see appendix III) the mean profit per visit is presented for each group. A strong increase in the mean profit over sessions can be observed for all groups. Subjects start with loosing about 1500 per visit and over sessions the profit per visit increases up to about gaining 1750 per visit. Indeed, this practice effect is highly significant (F=54.061, df = 96, p < .0001). There is no interaction effect of the begin- and end aiding (F=1.40, df = 5, p=.222) nor are there main effects of either the begin- or end aiding conditions (F = 2,73, df=1, p = .101 and F= .048, p =.827).

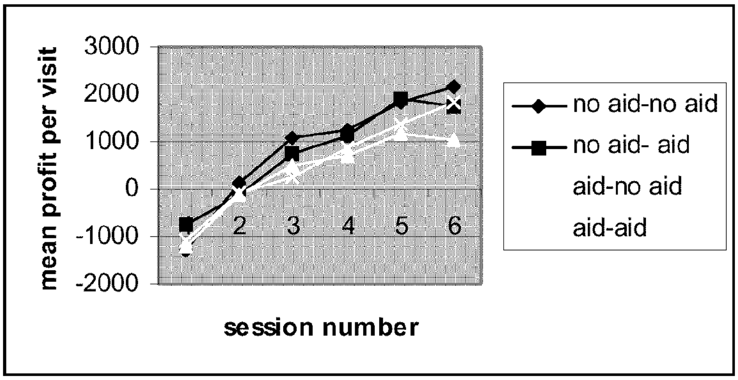

Figure 3.2: Overview of the subjects success score: mean profit per visit for each session and experimental group

Also, the interactions of practice and the aiding conditions are not significant (F=.641, df =5, p=.669 and F=1.117, df =5, p=.357). Finally, the second order interaction between practice and the begin and end aiding condition is not significant (F=2,168, df =5, p=.064). This means that in the aiding conditions the mean profit per visit is not higher than in the non-aiding conditions. If any: aid has a negative effect on performance in the subsequent non-aid session (negative transfer).

As mentioned there is a strong effect of practice on the mean profit per visit. The within-subjects (repeated) contrasts give some further insight in the differences between subsequent sessions. It appears that the difference between session 1 and 2 is highly significant (F=72.55, df=1, p<.001) as well as between session 2 and 3 (F=21.84, df=1, p<.001) session 3 and 4 (F=7.9, df=1, p=.006) and session 4 and 5 (F=14.47, df=1, p<.001). The difference between session 5 and 6 is not significant (F=1.20, df =1, p=.275). This means that in each subsequent practice session the mean profit per visit increases and which levels off only in the last session.

3.2 Bankruptcies. As mentioned subjects become bankrupt when the captain of a ship has insufficient money to make even one business travel. Figure 3.3 depicts the mean number of bankruptcies for the six practice sessions and for each of the experimental groups. As can be seen in the figure almost everyone becomes bankrupt in the first session. This clearly diminishes with practice and in the last session most subjects are able to survive throughout the session. The figure shows that in the last practice session the mean bankruptcies have dropped for all groups. A similar pattern is reflected in the median. The (main) effect of practice turned out to be significant (F=10.01, DF=96, p<. 001). This is mainly due to a significant decline between session 1 and 2 (F=32.77, DF=1 p<. 001). The increase from session three to four is slightly significant (F=4.12, DF=1 p=. 045).

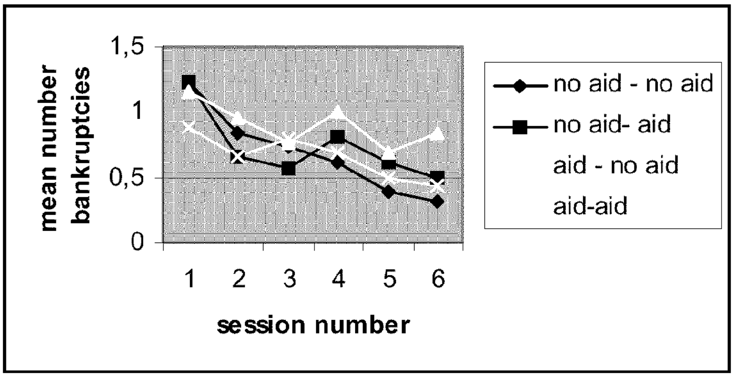

Figure 3.3: Overview of the subject's failure scores: mean number of bankruptcies per session for each of the experimental groups

3.3. Number of visits per session. As mentioned earlier, the speed of the decision making process is reflected in the number of visits that the subject can make in one experimental session. Figure 3.4 and Table 3.2 (see appendix IV) depict the total number of visits for the four groups in each of the six sessions. The figure shows two points: 1) the overall number of visits increases with practice in all conditions. Subjects start with about 60 visits per 1 ½ hour session. This doubles to about 120 visits per session. Indeed, the practice effect is highly significant ($F=45.80$, $df=96$ $p<.001$). 2) Aiding conditions show fewer visits as compared to no aiding conditions, somewhere between 15-30 visits per session. The figure shows a cross-over interaction between the aid-no aid and no aid-aid group. This effect appears to be highly significant ($F= 13.57$, $df=1$, $p<.001$). There is a main effect of the begin aid manipulation ($F=6.13$, $df = 1$, $p = .015$), an interaction effect of the begin-aid manipulation with practice ($F=7.09$, $df=5$, $p<.001$) and an interaction effect of the end aid effect with practice ($F=3.635$, $df=96$, $p=.005$). This means that memory aiding has a negative effect on the number of visits that subjects made. Without aiding the subjects begins with a relatively large number of visits and this discrepancy becomes even larger per session relative to starting with aiding. Removal of the aiding is accompanied with an increase of the total number of visits and introducing memory aiding is accompanied with a reduction in the total number of visits.

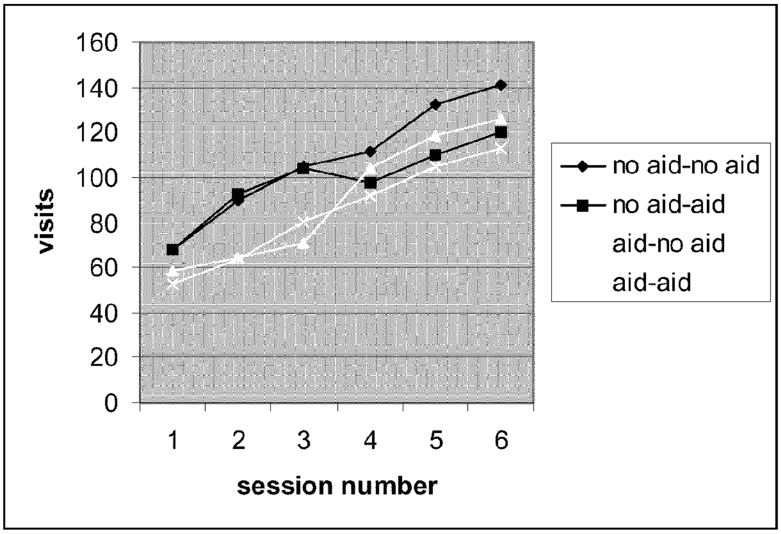

Figure 3.4: Overview of subjects decision speed score: Number of decision rounds (visits) per session for each of the experimental conditions

3.4. Amount of info. As mentioned earlier, subjects have the opportunity to search for information about the value of the prospects. Figure 3.5 and Table 3.2 (see appendix V) present the mean amount of purchased information per visit. The figure and table show that, in general, subjects search for only a limited amount of information, the average is always less then 1 request per visit. As can be seen in the figure subjects who start

in the no aid condition increasingly search for more information, up to twice as much as the subjects who started in the aid condition. Indeed, this interaction of the begin aid manipulation with practice is highly significant (F=3,791, df=96 p=.004). There is also a main effect of practice (F=8.54, df =5, p <.001) and a main effect of the begin aid manipulation (F=.308, df=96, p=.907).

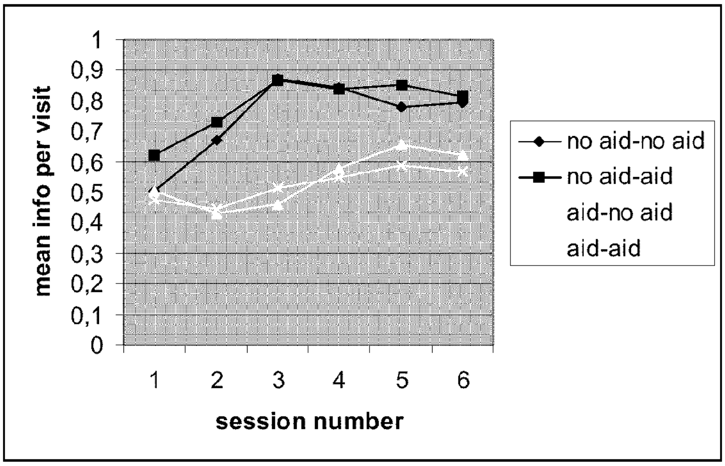

Figure 3.5: Overview of subject's info uptake: Mean amount of info per visit for each of the experimental conditions

(F=8.50, df=1, p<.001) while there is no practice interaction with the end aid manipulation and nor a main effect of the end aid manipulation (F=.917, df=5, p=.473). This means that there is a strong transfer effect of the begin aid condition on the amount of information that is purchased in the last 3 sessions: Starting in the aid condition subject search for relatively little information in the first three sessions, this does not change when aiding is removed in the last three sessions. On the other hand, starting in the no aid situation subjects search for more information in the first three sessions, however this does not change when aiding is introduced in the last three sessions.

3.5. Type of information. A final analysis concerns the pattern of information types that subjects purchase. As mentioned earlier subjects can search for information concerning the value of local or global alternative prospects (which we label: 'local' vs 'global'). They can also purchase information concerning the future value of the prospect (which we will label: 'future'). In contrast they can focus only on the value of the prospect which is currently being offered (labeled:'imminent'). Alternatively, subjects can purchase the information only after the decision is already made (labeled: 'after'). A general overview of these results is presented in table 3.4 for each of the information types over all sessions and groups. In the table figure it can be seen that subjects generally neglect information concerning the future value of prospects.

Table 3.4: Mean and median (in brackets) amount of purchased information type

Info type	Mean
After	.36 (.29)
Imminent	.17 (0)
Future	.01 (0)
Local	.03 (0)
Global	.05 (0)

Subjects generally do not search for information concerning local and global alternatives. These three types of info are hardly ever purchased; the means are .05 or less while the median value for each of these three information types is zero. There is too little variation in the data for these variables to examine to differences over sessions and groups. When subjects do buy info it is about the imminent option (mean value .17), but more particularly about the value of the products they have just purchased. That is: after the decision is made (mean value .36). Indeed, subjects buy more information after the decision than before the decision ($t=6{,}13$ $df=103$, $p<.001$).

4 Discussion

Several conclusions can be drawn from this experiment on practice and memory aiding in C2 decision processes. First, practice has a positive effect on decision performance. It increases the success score for each decision. It increases the overall decision speed and decreases the overall failure score. Second, memory aiding does not influence the mean success score for each decision, nor does it influence the overall failure score. If any: aid spoils performance in the subsequent non-aid session (negative transfer). Moreover, it slows down the decision speed considerably. Third, practice leads to an increase of the amount of information that subjects search for. Fourth, memory aiding in general has a negative effect on the search for information. Fifth, the amount of information that subjects searched for per decision is less than 1 request. Sixth, subjects search more information after the decision than before making a decision. Zeventh, subjects do not look for alternatives and neglect information about future developments of the system.

One of the earlier mentioned problems of the experimental studies with simulated C2 environments was that the C2 task should neither be too complex nor too simple. From subjects' performance measures of success, failure and speed it can be concluded that in general the C2 task used in this study was not too easy nor too difficult. The failures scores (bankruptcies) dropped considerably over sessions, but subjects failed until the last session. No effects of aiding were found on the failure scores. In each session subjects decisions were more successful in terms of the success score (profit) and this levels off, but not until the final session, which suggests that they reached their success 'peak' only in the last session. As mentioned earlier the mean success score per visit (profit) was used in the statistical analysis. A suggestion for a further more detailed analyis would be to use a time series analysis on the profit score. This may provide further insight into the more detailed differences between the experimental groups.

However, one should be careful in concluding that aiding has no effect on overall success performance, since aiding in general reduced the total number of decisions that were made in a session. This means, that if a subject makes 2000 profit units per decision and his total number of decisions decreases, then that subject will end up with less profit. Thus, aiding may not seem to influence the mean success score per decision, it does have however a negative effect on the overall success score per session.

The effect of aiding on decision speed, i.e. the total number of decision made in a period of time is both intricate and clear. In Figure 3.3 it can be seen that in general subjects were able to make more decisions per session up to the very last round. As a result of aiding subjects make less decisions relative to the no-aid group, about 20-25% less decisions per session. Introducing aiding to a group that was used to work without aiding resulted in a decline in the number of decisions. Similarly, removing the aid from a group that was used to work with it resulted in a clear increase in the number of decisions made. There did not appear differences in the mean success score per decision. It is plausible that memory aiding may lead subjects to spending too much time in trying to structure the decision problem. They may spend relatively much time in the uptake of information and the constructing of problem representation. Subjects may also grind too much on the information and actually think too much, at least too much relative too what the dynamics of the situation allow. If that is indeed the case, memory aiding turns out to be more like a burden than a support.

This points out a warning for introducing aiding techniques in decision making environments in general without sufficient research. An obvious means of help may become a burden in disguise. Many subjects in the no aiding condition mentioned: 'I can never do this task without paper and pencil'. Although this is only a qualitative observation, it illustrates our point. It may sound trivial that supporting working memory, by giving subjects some more storage capacity should be helpful; yet the results show that it was otherwise and

deteriorated human decision performance. Therefore, potential decision support techniques should first be tested in simulated lab studies before they can be applied in active service. It could be that providing more strorage capacity promotes more extended considerations which are actually not helpful.

An important question in this study concerns the amount of information subjects require to know about the value of a certain prospect. In the simulation the prospects were buy offers at a trading centre at a particular moment. The subjects were left in continuous uncertainty about the local, global and future values of the prospects. In order to remain updated constant information has to be obtained on changes in supply and demand. In our C2 task simulation subjects evaluated three prospects per decision round. Our results show that subjects purchased on the average less than 1 piece of information concerning the local, global or future values of all three prospects. Although the results show that practice does increase and almost doubles the total profit, the conclusion must be that on many occasions the subjects makes a decision without searching for any value of prospects at all.

Memory aiding had a negative effect on the amount of information that is searched for. More specifically, as Figure 3.4 shows, it is what they receive first, aiding or no aiding, what matters most. Subjects who started with aiding, searched for relatively less information compared to subjects who started without aiding. Removing aiding, however, did not increase the amount of information search. And vice versa, introducing memory aiding did not reduce it. How can this pattern of results be explained? First, it is plausible to relate these observations to the hypothesis that memory aiding makes the decision maker spend too much time in problem structuring. Following this conjecture, it is likely that subjects who start with aiding spend too much time or think too much about each piece of information they purchase. As a consequence they have less time to purchase information and consequently the mean amount of purchased information is less compared to the no aid condition. Second, once the subjects have adopted a certain information search profile, it is plausible to assume that adding or removing the memory aiding does not lead to a structural change in information search strategy. What happens is that both groups simply continue using their adopted search strategy, but become either slower or faster. In the condition of removal of the aid subjects will start making more decisions, and in the condition of adding the aid the number of decisions decreases.

The results on the information search profiles show a final important finding. Table 3.5 shows that subjects do not search for local or global alternatives; nor do they search for information concerning the future value of a prospect. It is striking that subjects neither searched for alternative options nor seemed to incorporate information about the future value of prospect into their decision making process. Such information could have given further insight on potential alternatives or future disasters or fortunes, but it was practically not searched for. Thus one could argue that subjects did actually not decide, since decision making requires that subjects choose between alternatives (Baron, 1994; Hogarth, 1987). In contrast subjects mainly evaluated available opportunities. They decided by evaluating the prospects one at a time, and rejected or accepted each option sequentially. Moreover, they bought more information after than before the decision. In other words: the general decision strategy can be described as: satisfy and justify. With a minimal amount of information they choose the 'first acceptable' option and used information afterwards to justify the decision. Such a strategy may lead to sub-optimal results: indeed most subjects had a significant failure score in the first sessions. Due to practice, however, subjects successfully adapted their strategy to the dynamics of the environment.

An important question is why subjects downgrade information about the future developments of the system. Why is imminent information overvalued, or is it really? One explanation is that the task was too complex. To incorporate the future values of prospects may have been just beyond the processing capacity of a single individual, especially under time stress. Another explanation is that subjects fail too see the importance of future developments. A third and not unrelated explanation can be found by relating this finding to the literature on time preference and inter-temporal choice (Loewenstein & Elster, 1992; Roelofsma, 1996). A well described phenomenon in this literature is that subjects downgrade future consequences. Immediate outcomes are overvalued because subjects view the future as uncertain. The conjecture has not been extended to the evaluation of timing of information, or the resolution of uncertainty of information. It is plausible, that subjects do not search for future information because they perceive this information to be less certain.

Our results provide some hints with regard to some major problems that could be faced by operators of complex systems, like military C2. In this respect it offers some guidelines to those issues that should be focussed on and that require further study. A major result of this experiment is the finding that memory aiding may slow down the decision making process and have a negative effect on the overall decision performance. Aiding techniques should therefore be carefully and systematically examined in experiments with simulated C2 task environments before put to practice. Another major finding of our experiment was that subjects attend only to a limited number of information concerning the value of a prospect. Although practice was helpful, the improvement was not striking since most of the information was used to justify the decision. As a result of technological advances there is a tendency to feed C2 systems with increasingly more information. Giving our findings it is more reasonable to carefully examine each piece of information that is put in the system. It is important to know whether and how the operator uses this information in the decision process before it is fed into the system. The presence of abundant information may deteriorate decision performance and the information search in a number of ways. The effects of redundant and irrelevant information in C2 as well as the above mentioned effects of the time frame of the information (imminent vs remote) definitely requires additional research that could not be conducted in the context of the present project.

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APPENDIX I

In this experiment you will participate in a management command control simulation. There are six different commodities that can be traded and six different trading centres that can be visited. These centres are located at different stars centres in space. The commodities are: Food , computers, deuterium, platinum, machines and preciosa. Each centre deals with all six goods, but the prices are different at each centre and they are continuously changing as well. Moreover, a centre either buys or sell each commodity, but not both sell and buy the same product.

You are the commander of a fleet that transports commodities from one centre to the other in a competitive environment with another fleet. You will buy commodities in centre that supplies them and sell commodities to centres that have a demand. Your ultimate goal is to make as much profit as possible. For this reason you have to buy at the lowest price and sell at the highest price.

As mentioned you are the commander of the fleet. You can use the ships to transport the goods from one centre to the another. When a ship arrives at a centre you can first sell the commodities that are demanded. Then, you can buy commodities that are offered at the centres and that you want to transport to another centre. When you have finished your transactions you have to decide your next travel destination, that is you have to indicate which centre you will visit next. However, you can not leave a centre unless you have sufficient fuel supplies. So, pay attention to having sufficient capital to afford the travel costs. These travel cost are influenced by:

a) The fuel price (this may change over time)

b) The weight of the ship's cargo. The transaction are made in a unity called 'kugel'. However kugels differ in weight for each commodity. You can see the current ship's weight of the commodity on the computer screen.

c) The travel destination. The longer the distance the higher the travel costs will be. You can look at your star centre map for the distances between centre. The current travel costs per 100 star miles is presented on your command and control screen.

You will control your fleet with a computer communication network that is directed by your command and control screen. The negotiations with the centres will also be with the command and control screen. Both sell- and buy prices are continuously fluctuating. The quantities expressed in kugels vary over time as well. The indicated prices are dependent on the demand on a particular moment. When a centre has bought an amount the demand of that particular product will decrease and the prices will also be decrease. That is, both prices and quantities fluctuate depending on the transaction pattern.

To simplify your decisions you can purchase information about quantities and prices. You can also ask information about the development of prices and quantities, supplies and supplies and contextual information of the centres by the news bulletin.

There are three types of information:

a) *Centre information.*

By providing the name of a star centre you will receive on your second command and control screen an overview of all the current prices and quantities that are being traded in that centre.

b) *Commodity information.*

By providing the name of a commodity you will receive an overview of current prices and quantities of a commodity at all centres.

c) *Bulletin information.*

Here you can receive information about 1) future developments of prices and quantities. The system is dynamic and prices and quantities change continuously. In some periods of time fluctuation in prices is large, at other times it is small. 2) Information about the development of the fuel price which can increase

or decrease. The travel costs are influenced by the fuel price. 3) Information about the future costs of information. 4) Information about the travel speed of the ship. The travel speed of your ship can be influenced by the condition of the machines and the environmental conditions. This info can help you decide whether or not to travel for long or short distances.

It is important to realize that the travel costs can increase considerably. Again, they are influenced by the weigh of your cargo and your travel destination. Their must be sufficient capital on board of a ship to pay these costs. If the travel costs exceed the cash that is available on a ship there will be two options for the commander:

1) change your travel destination
2) Resell products to the current starcentre. But please pay attention to the fact that the products are being resold only for half the original price.

It is important that to realize that you keep on trying to make as much profit as possible. There is a competing team which acts as an enemy of your company!

APPENDIX II

Table 2.1: Development of prizes, quantities, and game model

Development of prize, demand and supply:

Concerns.. Transaction	Prize on centre	Prize on other centre	Demand on Centrum	Demand on other centra	Supply on centrum	Supply on other centra
Centrum sold	Up	Down	n.a.	n.a.	n.a.	Up
Centrum bought	Down	Up	Down	Up	n.a.	n.a.

Some important formulae of the model behind the game:

Centrum buys/sells:	0.6 * stock
Development of stock:	Qn = Qo – PARQ * N * RAND
Development of prize in centre:	Pn = Po +PARAM * N * RAND (Buy: PARAM = -PARP) (Sell: PARAM = PARP)
Development of prize in the two other buying or selling centre:	dP = abs ((Po-Pn)/2) * RAND)
Development of stock in the two other buying or selling centre:	dQ = abs ((Qo-Qn)/2) * RAND)
Travelling-time of the ship:	weight * PART + distance * 0.1
Travelling-costs:	weight * distance * prize of gas + 1000
Prize of information:	PARI
Prize of fuel (gas):	PARG
Randomising:	Rand = random selection of (0.6, 0.8, 1.0, 1.2, 1.4)

During the simulation the parameters PARP, PARQ, PARG, PART en PARI are fluctuated according to the parameter table.

N = merchandized number   n = new value   o = old value

Each centre sells 3 commodities and buys 3 commodities.

Type of commodity to sell or buy differs on each centre

APPENDIX III

Table 3.1: Subjects success score: Mean amount of profit per sessions for the experimental groups and sessions. The medians are printed in brackets

SESSION	1	2	3	4	5	6	TOTAL MEAN
No aid-No aid	-1290.63 (-1594.51)	137.84 (380.82)	1102.90 (1092.95)	1242.77 (1212.27)	1818.55 (2065.88)	2175.32 (2078.62)	864.46
No aid- Aid	-753.82 (-1431.33)	-129.01 (-705.22)	770.30 (1086.44)	1137.33 (1345.25)	1906.18 (1868.75)	1737.59 (1677.58)	778.10
Aid-No aid	-1197.97 (-1331.62)	-132.50 (-711.30)	482.91 (-24.41)	705.10 (30.80)	1162.31 (1411.33)	1038.53 (1518.55)	343.06
Aid-Aid	-1095.65 (-1499.74)	-68.23 (-816.05)	258.60 (326.39)	878.53 (551.42)	1374.34 (1608.79)	1840.71 (1739.91)	531.38
TOTAL MEAN	-1084.52	-47.98	653.68	990.93	1565.35	1698.04	

APPENDIX IV

Table 3.2: Subjects decision speed score. Mean amount of decision rounds (visits) per sessions for the experimental groups and sessions. The medains are printed in brackects

SESSION	1	2	3	4	5	6	TOTAL MEAN
No aid-No aid	67.73 (62.50)	89.46 (89.50)	104.65 (98.50)	111.42 (102.50)	132.50 (126.50)	141.04 (131.50)	107.8
No aid- Aid	68.08 (62.50)	92.73 (99.50)	104.62 (88.50)	97.46 (91.00)	110.27 (104.50)	119.92 (110.00)	98.85
Aid-No aid	58.46 (50.00)	64.08 (64.00)	70.92 (67.50)	104.19 (95.00)	118.65 (117.50)	125.77 (123.00)	90.35
Aid-Aid	52.73 (46.00)	64.00 (60.00)	80.19 (73.00)	92.19 (84.50)	104.65 (93.00)	113.04 (103.50)	84.47
TOTAL MEAN	61.75	77.57	90.10	101.32	116.52	124.94	

APPENDIX V

Table 3.3: Mean amount of information that subjects search for about the value of a prospect for the experimental groups and sessions. The medians are printed in brackets

SESSION	1	2	3	4	5	6	TOTAL MEAN
No aid-No aid	.51 (.53)	.67 (.67)	.87 (.74)	.84 (.82)	.78 (.67)	.80 (.74)	.75
No aid- Aid	.62 (.50)	.73 (.66)	.87 (.77)	.84 (.78)	.85 (.72)	.81 (.69)	.79
Aid-No aid	.51 (.49)	.43 (.22)	.46 (.20)	.58 (.51)	.66 (.59)	.62 (.63)	.54
Aid-Aid	.48 (.40)	.45 (.40)	.51 (.43)	.55 (.48)	.59 (.50)	.57 (.44)	.53
TOTAL MEAN	.53	.57	.68	.70	.72	.70	